CHAPTER 2

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN
REMOVAL OF NITRATE BY REVERSE OSMOSIS
AND NANOFILTRATION

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLES

FIGURES

1.0 INTRODUCTION

1.1 Background

This document is the ETV Testing Plan for Reverse Osmosis and Nanofiltration Processes for the Removal of Nitrates from Contaminated Water. This Testing Plan is to be used as a guide in the development of Product-Specific Test Plan (PSTP) procedures for testing reverse osmosis and nanofiltration (RO/NF) treatment equipment, within the structure provided by the ETV Protocol Document for nitrate removal. Refer to the Test Plans for Equipment Verification Testing for Physical-Chemical Removal of Nitrate by Ion Exchange and Membrane Processes for further information.

This document is applicable only to pressure-driven membrane processes such as RO/NF. This document is NOT applicable to electrically-driven, thermally-driven, or concentration-driven membrane processes.

Standard pretreatment such as cartridge filtration and acid and/or antiscalant addition included in a RO/NF treatment system that is to be evaluated for removal of nitrates is considered an integral part of the treatment system. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes.

Additional pretreatment processes which may be required to reduce particle loading to the RO/NF system for surface water applications are considered to be a separate treatment module whose performance and operation are outside the scope of this document. Where such pretreatment is required to meet reduce the fouling potential of the RO/NF feedwater as measured by silt density index and turbidity values.

In order to participate in the equipment verification process for RO/NF processes, the Equipment Manufacturer shall retain an NSF-qualified Field Testing Organization (FTO) to employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of the PSTP. The procedures shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

2.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan will be contracted with a state-certified or third party- or EPA-accredited laboratory.

The FTO shall provide full detail of the procedures to be followed for each task in the PSTP. The FTO shall specify the operational conditions to be evaluated during the Verification Testing.

3.0 OVERVIEW OF TASKS

This ETV Testing Plan is divided into 6 tasks. A brief overview of the tasks to be included in the verification testing program is presented below.

3.1 Task 1: Characterization of Feed Water

A full characterization of the source water must be made prior to initiating operation so that the potential for fouling and mineral precipitation (scaling) can be defined. Results of this analysis will be used to define feedwater pretreatment requirements and system operating conditions, and to identify potential foulants in the source water for monitoring during operation.

3.2 Task 2: RO/NF Performance

The objective of this task is to evaluate RO/NF operation. RO/NF productivity and the rate of fouling will be evaluated in relation to feed water quality. The relative fouling rates will be used, in part, to evaluate operation of the RO/NF equipment under the flux and recovery conditions to be verified.

3.3 Task 3: Product and Waste Water Quality

The objective of this task is to evaluate the quality of water produced by the RO/NF system, referred to as product water or permeate. Multiple water quality parameters will be monitored during each operational period. A basic goal of this Task is to confirm that RO/NF-treated waters meet the manufacturer's statement of performance objectives for nitrate. Permeate quality will be evaluated in relation to feed water quality and operational conditions. The waste water (concentrate) stream will also be characterized.

3.4 Task 4: RO/NF Cleaning

An important aspect of RO/NF operation is the restoration of membrane productivity after fouling has occurred. The objective of this task is to evaluate the efficiency of membrane cleaning. Normalized product flow, normalized salt passage, and differential pressure before and after cleaning will be used as the primary criteria for evaluation of cleaning effectiveness.

3.5 Task 5: Data Reduction and Presentation

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the FTO and NSF for data obtained during the

Verification Testing.

3.6 Task 6: Quality Assurance/Quality Control

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during Verification Testing.

4.0 TESTING PERIODS

If the source water is a groundwater which exhibits little or no significant changes in seasonal water quality, the required operational tasks in the Verification Testing Plan (Tasks 1-4) shall be performed once (minimum) or twice (preferred) over a one-year period. Each test run, excluding equipment mobilization, startup/troubleshooting, and demobilization is to be based on a minimum of 1,000 hours of membrane system operation.

A schedule describing the sequence and duration of each of the required tasks is provided in Figure 1. In the rare event that the source water is a surface water, the operational tasks shall be performed for four weeks each quarter over a calendar year.

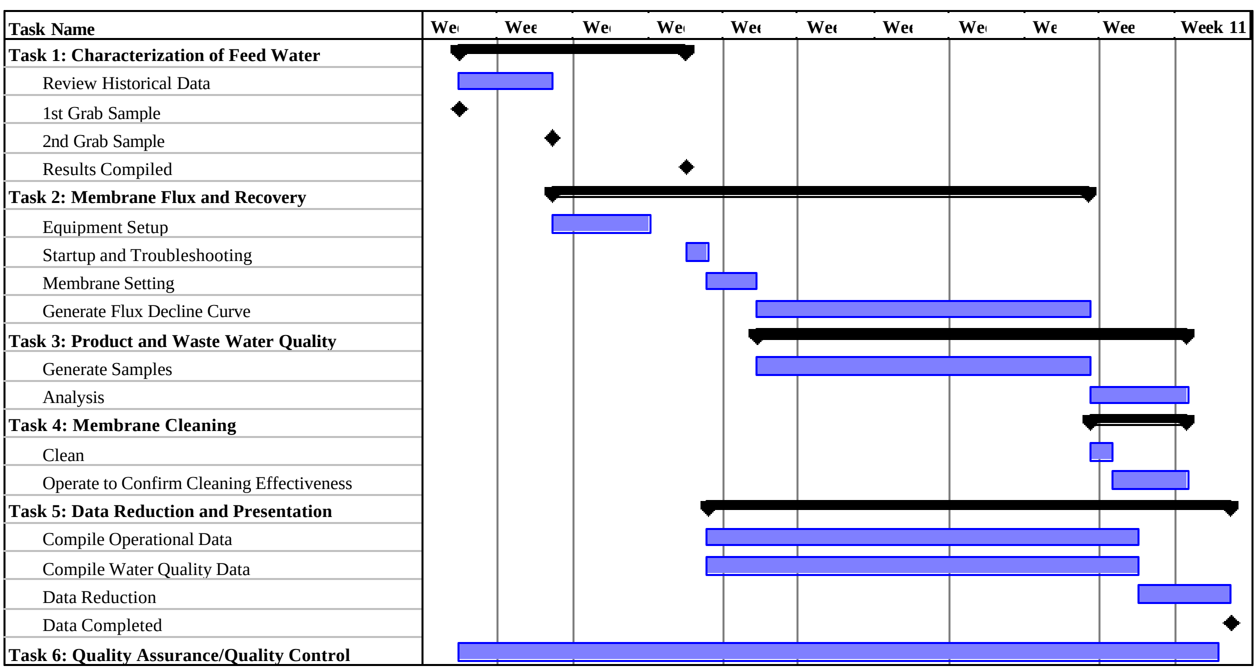

Figure 1 - Membrane Treatment System Verification Testing Schedule
(Single Test Period)

5.0 DEFINITION OF OPERATIONAL PARAMETERS

The following definitions are used to characterize performance of the RO/NF system.

5.1 Permeate: Product water produced by the RO/NF treatment system.

5.2 System Feedwater: Source water introduced into the RO/NF treatment system for treatment.

5.3 Element Feedwater: Water introduced into the RO/NF element, consisting of system feedwater for single-pass systems, or a combination of system feedwater and recycled concentrate for systems with concentrate recycle.

5.4 Membrane Fouling: A reduction in permeate flux caused by the accumulation of feedwater contaminants within or on the surface of the membrane or within or on the feedwater spacer. Fouling that can be restored by hydraulic or chemical means is termed "reversible" fouling. In contrast, "irreversible" fouling is defined as a permanent loss in permeate flux that cannot be restored by hydraulic or chemical means.

5.5 Stage: An assemblage of one or more pressure vessels, each containing between three and seven membrane elements, plumbed to receive a common feedwater. Each vessel receives approximately equal feed flow, produces approximately equal permeate and concentrate flow and operates at equal recovery.

5.6 Feedwater System Recovery: The ratio of permeate flow to system feedwater flow, expressed as a percentage:

$$\%\ System\ Recovery\ =\ 100\ x\left[\frac{Q_p}{Q_f}\right]$$

Where: Q_p = Permeate flow rate
Q_f = Feed flow rate to the membrane system

5.7 Membrane Element Recovery: The ratio of permeate flow to element feedwater flow, expressed as a percentage:

$$\%\ Element\ Recovery\ =\ 100\ x\left[\frac{Q_p}{Q_f\ +\ Q_r}\right]$$

Where: Q_p = Permeate flow rate
Q_f = System feed flow rate to the element
Q_r = Concentrate recycle flow rate to the element (if present)

5.8 Permeate Flux: The flow of permeate produced by the RO/NF system divided by the total membrane surface area of all elements in the system. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

Where:	J_t	=	Permeate flux at time t (gallons per square foot per day)
	Q_p	=	System permeate flow at time t (gpd)
	S	=	Membrane surface area (ft^2)

5.9 Salt Passage: The ratio of the concentration of any salt present in the permeate to its concentration in the feed stream, expressed as a percentage:

$$SP = \frac{C_p}{C_f} \ x\ 100$$

Where:	SP	=	Salt passage
	C_p	=	Permeate concentration for a given salt (mg/L)
	C_f	=	Feed concentration for a given salt (mg/L)

5.10 Temperature Adjustment for Permeate Flow and Salt Passage Calculations: Flow of water and salt through a RO/NF membrane is proportional to feedwater temperature based primarily on the viscosity of water. Permeate flow and salt passage must be corrected to a reference temperature of 25°C to enable an accurate determination of how changes in these parameters are affected by feedwater constituents according to the following equation:

$$J_{25} = \frac{J_T}{1.03^{(T-25)}}$$

Where:	J_{25}	=	Instantaneous flux at reference temperature of 25°C (gfd)
	J_T	=	Instantaneous flux at operating temperature T (gfd)
	T	=	Operating temperature (°C)

In many cases, membrane manufacturers have developed temperature correction factor (TCF) values specific to their membrane products that are more accurate than the equation shown above. Where available, the manufacturer-provided TCF should be used.

5.11 Feed-Concentrate Differential Pressure: The difference in measured pressure between the feed stream and the concentrate stream of a stage of the membrane array or of the entire membrane system. Expressed as an equation:

$$\Delta P = P_f - P_c$$

Where:	ΔP	=	Feed-concentrate differential pressure (psi)
	P_f	=	Feed stream pressure for a stage or the system (psig)
	P_c	=	Concentrate stream pressure for a stage or the system (psig)

5.12 Differential Osmotic Pressure: The difference in osmotic pressure between the feed and permeate streams. Osmotic pressure of the feed is defined as average osmotic pressure of the feedwater into and the concentrate out of the membrane system. Osmotic pressure is a measure of the force exerted by the natural tendency of water to flow across a semi-permeable membrane from a solution of lower salt concentration to a solution of higher salt concentration. Expressed as a formula:

$$\Delta \boldsymbol{p} = \left[\left(\frac{TDS_f + TDS_c}{2} \right) - TDS_p \right] x\ 0.01$$

Where:	$\Delta\pi$	=	Differential osmotic pressure (psi)
	TDS_f	=	Feedwater total dissolved solids (mg/L)
	TDS_c	=	Concentrate total dissolved solids (mg/L)
	TDS_p	=	Permeate total dissolved solids (mg/L)

5.13 Net Driving Pressure: The pressure available to drive water through the membrane, equal to the average feed pressure (average of feed pressure and concentrate pressure) minus the differential osmotic pressure, minus the permeate pressure. Expressed as a formula:

$$NDP = \left(\frac{P_f + P_c}{2} \right) - \Delta \boldsymbol{p} - P_p$$

Where:	NDP	=	Net Driving Pressure (psi)
	P_f	=	Feed pressure (psi)
	P_c	=	Concentrate pressure (psi)
	$\Delta\pi$	=	Differential osmotic pressure (psi)
	P_p	=	Permeate pressure (psi)

5.14 Normalized Product Flow: To clearly observe changes in permeate flux caused by membrane fouling or scaling, measured permeate flow must be corrected or "normalized" for variations in Net Driving Pressure and Temperature, using the following formula:

$$NPF = \frac{NDP_i}{NDP_t} x \frac{TCF_i}{TCF_t} x Q_p$$

Where:	NPF	=	Normalized product flow (gpm)
	NDP_i	=	Net Driving Pressure at initial conditions of operation (psi)
	NDP_t	=	Net Driving Pressure calculated at time t (psi)
	TCF_i	=	Temperature Correction Factor based on temperature at initial conditions of operation
	TCF_t	=	Temperature Correction Factor based on temperature at time t
	Q_p	=	permeate flow (gpm)

5.15 Normalized Salt Passage: To more clearly observe changes in the flow of any salt through the membrane caused by membrane fouling and scaling or changes in the permeability of the membrane itself from exposure to feedwater constituents, salt passage is normalized using the following equation:

$$NSP = \frac{NDP_t}{NDP_i} \; x \; \frac{C_{fb\,i}}{C_{fb\,t}} \; x \; \frac{C_{f\,t}}{C_{f\,i}} \; x \; SP$$

Where:	NSP	=	Normalized salt passage (%)
	NDP_i	=	Net Driving Pressure at initial conditions of operation (psi)
	NDP_t	=	Net Driving Pressure calculated at time t (psi)
	$C_{fb\,t}$	=	Feed-brine salt concentration at time t (see below)
	$C_{fb\,i}$	=	Feed-brine salt concentration at initial conditions of operation (see below)
	$C_{f\,t}$	=	Feed salt concentration at time t (mg/L)
	$C_{f\,i}$	=	Feed salt concentration at initial conditions of operation (mg/L)
	SP	=	Salt passage (%)

5.16 Feed-Brine Salt Concentration: The Feed-Brine salt concentration used in the calculation of Normalized salt Passage is defined by the following equation:

$$C_{fb} = \frac{\ln\left(\frac{C_b}{C_f}\right)}{1 - \left(\frac{C_f}{C_b}\right)}$$

Where:	C_{fb}	=	Feed-Brine salt concentration
	C_b	=	Brine (concentrate) salt concentration (mg/L)
	C_f	=	Feed salt concentration (mg/L)

6.0 TASK 1: CHARACTERIZATION OF FEED WATER

6.1 Introduction

This task involves a complete characterization of the raw water being fed to the treatment system. The information is required to determine the suitability of the water source as feed water for verification testing, and to document parameters which may be important in predicting the fouling and scaling tendencies of the water source.

6.2 Objectives

The objectives of this task are as follows:

- Obtain a complete chemical and physical characterization of the source water or feed water that will be subject to treatment.

- Identify potential membrane foulants and scalants (turbidity, bacteria, sparingly soluble salts, etc.) that will determine the type and degree of feedwater pretreatment and that must be monitored during system operation.
- Verify that the water as sampled is representative of the source water based on historical data (where available).

6.3 Work Plan

This Verification Testing Plan is based on the assumption that RO/NF for nitrate removal will be predominately applied to groundwaters that are not subject to significant seasonal changes in water quality. Application of membrane treatment systems to surface waters requires a significantly different approach than that outlined here in order to address seasonal variations in water quality.

Most water sources will not have pre-existing water quality data of sufficient detail to allow an evaluation of the proper application of RO/NF. Completion of this task involves the following:

- Analysis of grab samples for a detailed water quality analysis. The parameters evaluated will allow calculation of a complete cation/anion balance, in addition to general physical/chemical measurements and limited microbiological and organic analysis.
- A review of selected historical water quality data, where available. This will allow determination of trends in key water quality parameters such as nitrate and TDS or conductivity, as well as allowing verification that the water quality measured by the grab samples is representative of the recent historical data.
- Calculation of the scaling potential of the source water to be treated. This includes estimating the concentrations of the following salts in the membrane concentrate stream at the membrane system operating conditions proposed by the Manufacturer in Task 2 to the degree, if any, that these salts will be present in the concentrate stream in excess of their theoretical solubility:
  - calcium carbonate
  - calcium sulfate
  - barium sulfate
  - strontium sulfate
  - calcium fluoride
  - Silica

The FTO shall include in the PSTP guidelines for maximum percent saturation for each of the above salts during RO/NF system operation assuming the use of appropriate scale inhibiting chemicals.

6.4 Analytical Schedule

Parameters required for a complete evaluation of source water quality are presented in Table 1. Table 1 identifies required and optional parameters for evaluation by analysis of grab samples.

Table 1
Raw Water Characterization

Parameter	Grab Samples
General/Physical Parameters	
Temperature	Required
pH	Required
TDS	Required
Conductivity	Required
Silt Density Index	Required
Turbidity	Required
Particle Counts	Optional
Color	Optional
Taste and Odor	Optional
Inorganic Cation/Anion Balance	
Ca^{+2}	Required
Mg^{+2}	Required
Na^{+}	Required
K^{+}	Required
NH_4^{+}	Optional
Sr^{+2}	Required
Ba^{+2}	Required
Fe^{+2}	Required
Mn^{+2}	Required
CO_3^{-2}	Required
HCO_3^{-}	Required
SO_4^{-2}	Required
Cl^{-}	Required
NO_3^{-}	Required
F^{-}	Required
CO_2	Required
H_2S	Optional
SiO_2	Required
Organic/Microbiological	
Total Organic Carbon	Required
Total Coliforms	Optional
Heterotrophic Plate Count	Required
UV absorbance (@254 nm)	Optional
AOC/BDOC	Optional

(1) Report the mean and standard deviation of a mini-mum of two grab samples taken at least 10 days apart.

Parameters to be analyzed from grab samples should be taken from a minimum of 2 samples taken at least 10 days apart. Potential sources of historical data include the United States Geological Survey, US Environmental Protection Agency, and state and local laboratories.

Manufacturers intending to have their equipment verified for uses other than nitrate removal may wish to characterize the source water in terms of additional parameters besides those identified in Table 1.

6.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance objectives. The feed water should challenge the capabilities of the equipment with respect to nitrate concentration but should not be beyond the range of water quality suitable for treatment for the equipment in question.

The detailed water quality analysis results will allow an estimation of which sparingly soluble salts, if any, present a potential for scaling by mineral precipitation at the water temperature and recovery conditions to be tested. The analysis will allow proper selection of the chemical pretreatment (acid addition and/or antiscalant addition) and the design recovery of the RO/NF system. The water quality analysis will also determine if feedwater pretreatment is required to reduce fouling tendency. If turbidity or silt density index values exceed membrane-industry accepted criteria or if microbiological indicators suggest that biological fouling potential is significant, the Manufacturer will be required to provide pretreatment to adequately address these concerns.

7.0 TASK 2: RO/NF PERFORMANCE

7.1 Introduction

The purpose of this task is to verify that the RO/NF system, when tested in accordance with Manufacturer-selected operating conditions on the selected source water, can maintain performance as defined by:

- Productivity (product flow)
- Permeate nitrate concentration (and other salts, if applicable)
- Feedwater system recovery over a specified period of operation

A further purpose of this task is to demonstrate that changes in the level of these performance characteristics caused by membrane fouling or other interactions between the RO/NF system and the feedwater can be adequately managed through chemical cleaning of the membrane elements at an acceptable frequency.

In this task, the RO/NF system will be operated at conditions of constant permeate flux and recovery as specified by the FTO, and the normalized product flow, normalized salt passage (as measured by conductivity) and their changes with operating time will be measured. As fouling occurs and normalized product flow declines or normalized salt passage increases to pre-determined values (proposed by the FTO and agreed to by NSF), the RO/NF system will be chemically cleaned per Task 4 to remove foulants and if possible, scalants. The efficiency of cleaning will then be assessed by measuring the degree to which normalized product flow has been increased and/or normalized salt passage has been decreased upon subsequent operation of the RO/NF system.

In the event that fouling rates are judged to be excessive and/or chemical cleaning efficiency less than desired, the Manufacturer shall propose revised operating conditions to reduce fouling rate. The effect of the new conditions of membrane productivity will then be determined by additional testing.

Prior to the start of the Verification Testing Program, the operational conditions to be verified shall be specified by the FTO in terms of an average permeate flux (gfd), feedwater recovery, and maximum salt passage (or its converse, minimum salt rejection) at a reference temperature of 25°C.

The degree of fouling or scaling that occurs within a RO/NF system is a function of source water quality and operational conditions. Waters with high particle loads or greater concentrations of sparingly soluble salts generally produce increased fouling and scaling. Feedwater, permeate and concentrate streams will be sampled for water quality parameters critical to the assessment of membrane productivity as they relate directly to fouling or scaling potential. This sampling will be conducted in conjunction with sampling performed under Tasks 1 and 3. Flow, temperature, pressure and conductivity data shall be collected to quantify changes in the following parameters:

- Normalized product flow
- Normalized salt passage
- Feed-concentrate differential pressure

The testing runs conducted under this task shall be performed in conjunction with Tasks 3 and 4. With the exception of additional testing periods conducted at the FTO's discretion, no additional RO/NF test runs are required for performance of Tasks 3 and 4. This task shall be performed once (minimum) or twice (preferred, within a one-year period, with a minimum of 6 months between test runs).

7.2 Objectives

The objectives of this task are to document the following:

- Operational conditions for the RO/NF system.
- Feedwater system recovery achieved by the RO/NF equipment.
- The rate of change in normalized product flow, salt passage and feed-concentrate differential pressure and associated operating times between cleanings based on these rates.

Verification of RO/NF system operation shall also apply to operating conditions that are considered less stringent than those conditions tested; examples of less stringent conditions would include operation at lower membrane flux (lower permeate flow) and lower product water recovery.

7.3 Work Plan

The PSTP shall specify information concerning design and operation of the RO/NF treatment system being evaluated, using the following categories as specified in Table 2:

- System design criteria
- Operating conditions (including those for pretreatment and RO/NF systems)
- Written procedures for operation and maintenance
- Cleaning Criteria. Specify allowable changes to the following parameters, which indicate a need for cleaning of a stage of the array or the entire system:
  - Percent loss of normalized product flow

$$NPF\ \%\ Loss = \frac{NPF_{Original} - NPF_{Fouled}}{NPF_{Original}}$$

  - Percent increase in normalized salt passage

$$NSP\ \%\ Increase = \frac{NSP_{Fouled} - NSP_{Original}}{NSP_{Original}}$$

  - Percent increase in feed-concentrate differential pressure (across each stage and/or the RO/NF system)

$$\Delta P\ \%\ Increase = \frac{\Delta P_{Fouled} - \Delta P_{Original}}{\Delta P_{Original}}$$

After startup of the RO/NF equipment, membrane operation should be established at the permeate flux and recovery conditions to be verified. In the event the temperature of the feedwater differs significantly from 25°C, the Manufacturer shall provide a temperature-specific permeate flux (normalized to account for differences in temperature between Manufacturer-specified and actual). The RO/NF system may be operated for up to 24 hours to allow the membrane elements to come to equilibrium prior to the start of data used in the flux decline calculations (membrane setting).

Following the membrane setting period, the treatment system should be operated until one or more of the cleaning criteria specified in the PSTP are met or a total of 1,000 hours of run time is achieved (whichever occurs first). The objective of operation is to attain 1,000 hours or operation without the need for chemical cleaning. If the rate of change in normalized product flow, normalized salt passage or feed-concentrate differential pressure results triggers one or more cleaning criteria before the 1,000-hour operating period is complete, chemical cleaning shall be performed per Task 4 and adjustments to operation shall be made to reduce the rate of change in these performance parameters (such as a decrease in permeate flux or feedwater system recovery).

Decisions on operating condition adjustments shall be made based upon the Manufacturer's experience and consultation with the FTO responsible for performing the study. If subsequent operation at the new conditions results in the need for a second cleaning prior to the attainment of 1,000 operating hours, chemical cleaning shall again be conducted and cleaning efficiency determined. RO/NF system operating conditions shall then be further adjusted to provide for an acceptable rate of change to attain 1,000 hours of operation between cleanings. Each recommended change in operating conditions shall be first approved by NSF and the FTO.

During operation, data for the operational parameters identified in Table 3 should be monitored and recorded either continuously by means of on-line instrumentation, or at a minimum of twice daily by manual measurement. Requirements for water quality monitoring during operation are presented in Task 3.

Additional testing may also be included in the PSTP in order to demonstrate RO/NF performance under different feedwater quality conditions. The FTO shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 1,000-hour testing period, as required above for each additional set of operating conditions.

7.4 Analytical Schedule

A sample matrix of operation monitoring points, parameters, and frequency for a typical two-stage RO/NF treatment system with concentrate recycle (see Figure 2) is presented in Table 3. The manufacturer should adopt the operational data collection locations to the particular geometry of the RO/NF system. In general, adequate data must be documented to allow evaluation of each stage of the system independently, as well as documenting operation of the treatment system as a whole.

7.5 Evaluation Criteria

Provide tabular data for the parameters listed in Table 3.

Provide graphs of the following parameters versus elapsed run time:

- Temperature
- Flux
- Recovery
- Feed Pressure
- Normalized product water flow
- Normalized salt passage
- Feed-concentrate differential pressure (across each stage)

Table 2
Membrane Treatment System Information to be Provided in Manufacturer PSTP

Parameter, units		Comments
System Configuration		
	Number of stages	
	Number of pressure vessels in each stage	
	Number of membrane elements per pressure vessel	
	Surface area per membrane element, Ft^2	
	Acid addition	Type and dose
	Antiscalant addition	Type and dose
	Cartridge filtration, µm	Nominal rated pore size
	Other pretreatment	Describe if used
Operating Conditions to be Evaluated		
	Recovery per stage, %	
	Recovery for system, %	
	Design flux, gfd	
	Feed water temperature	
	Feed water pH	
	Feed water nitrate concentration	
	Feed water TDS	
	Concentrate recycle rate, gpm or %	
Operations and Maintenance Procedures		
	System startup	
	Normal operation	
	Temporary system shutdown (flush)	System shutdown < 48 hours
	Prolonged system shutdown (preservation)	System shutdown >48 hours
Cleaning Criteria		
	Allowable normalized product flow decline, %	Percent reduction from initial value
	Allowable increase in differential pressure, %	Percent increase from initial value
	Allowable normalized salt passage increase, %	Percent increase from initial value

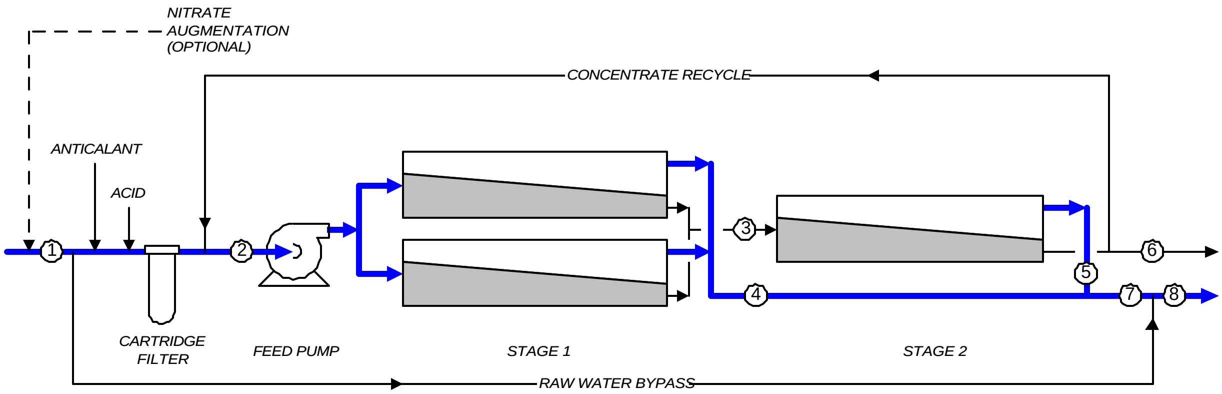

Figure 2 - Sample Monitoring Points for 2-Stage Treatment System with Concentrate Recycle and Raw Water Bypass

Table 3
Sample Operational Data Collection Matrix

	Monitoring Location (Refer to Figure 2)(1)	**Temper-ature**	**Flow**	**Pressure**	**Conduct-ivity**
1	Raw Water				
2	Membrane Feed Water				
3	Stage 1 Permeate				
4	Stage 1 Concentrate				
5	Stage 2 Permeate				
6	System Concentrate				
7	System Permeate				
7	Blended Product Water				

(1) Adopt the operational data collection locations to the particular geometry of the membrane system

(2) [shaded cell] indicates no monitoring requirement

7.6 (Optional) Nitrate Spiking

If the nitrate concentration at the test site does not challenge the treatment system to the limits of its performance objectives, an optional nitrate augmentation procedure may be used after the required 1,000 hour operating period is completed. Nitrate spiking would allow demonstration of product water quality under conditions of elevated nitrate in the feed water.

To spike nitrate, use of an appropriate spiking solution and metering pump will be required. A solution prepared from a monovalent nitrate salt (sodium nitrate, potassium nitrate) is preferred to avoid inadvertent addition of a cation that might increase the scaling potential of the test water. Use of nitric acid as nitrate source is not recommended because it would interfere with proper documentation of the acid dose required to prevent scaling.

Where nitrate spiking is proposed, the FTO must detail procedures for preparation of the spiking solution, and procedures for proper mixing of the spiking solution into the feedwater. The spiking solution must be added to the feed water prior to any other chemical addition (acid or antiscalant), prior to the point of concentrate recycle into the feed water (if used), and prior to raw water bypass for permeate blending. Refer to Figure 2 for an example of a proper spiking solution addition point.

Where nitrate spiking is proposed, the FTO may choose to operate over a range of feed nitrate concentrations. For each target nitrate concentration to be tested, the system should be operated for at least 5 days (120 hours) to allow steady-state performance to be achieved.

8.0 TASK 3: PRODUCT AND WASTE WATER QUALITY

8.1 Introduction

This task involves a characterization of product and waste quality during the system operation described in Task 2. Product water analysis will serve to document that the treatment system meets the nitrate removal performance criteria for which the manufacturer is seeking verification. Additional water quality information is required to identify performance of the treatment system relative to any potential foulants identified during the raw water characterization performed in Task 1.

The quality and quantity of concentrate produced by the RO/NF treatment system is a very important consideration in determining the efficacy and cost-effective use of the RO/NF treatment system. Regulators responsible for permitting the safe and environmentally acceptable disposal of the concentrate typically require precise information regarding physical, chemical and microbiological characteristics, along with other information relating to the biotoxicity of the concentrate. Costs for concentrate disposal can be significant based on the type of disposal option selected, particularly for those not utilizing a direct discharge to a surface water body.

8.2 Objectives

The objectives of this task are as follows:

- Assess the ability of the RO/NF equipment to meet the water quality goals specified by the Manufacturer.

- Monitor the concentrations of any potential foulants and sparingly soluble salts that may interfere with the long-term operation of the treatment system. Examples include turbidity, calcium, alkalinity, and bacterial plate counts in the feed water as identified in Task 1.
- Characterize the volume and composition of the wastewater (concentrate) produced by the process.

8.3 Work Plan

Water quality data shall be collected for the RO/NF treatment system feedwater, permeate and concentrate as shown in Table 4, during the RO/NF test runs of Task 2. At a minimum, the required sampling schedule shown in Table 4 shall be observed by the FTO on behalf of the Manufacturer. Water quality goals and target removal goals for the RO/NF equipment shall be clearly delineated in the PSTP.

A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 4. The actual water quality parameters selected for testing and monitoring shall be stipulated in the PSTP. The limiting salt cation and anion listed in Table 4 shall be determined from source water analyses and estimation of concentrate stream concentrations of the sparingly soluble salts as required under Task 1. Each salt that has been determined to be present in the concentrate at levels exceeding theoretical solubility or for which chemical conditioning of the feedwater is required to control solubility shall be monitored per the requirements of Table 4.

The FTO shall identify the treated water quality objectives to be achieved in the statement of performance objectives of the equipment to be evaluated in the Verification Testing Program. The statement of performance objectives prepared by the FTO shall indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater.

Although this Verification Testing Plan and the associated protocol are oriented towards removal of nitrate, the Manufacturer may desire to evaluate the treatment system's removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the FTO (refer to Table 5). Analysis of the remaining water quality parameters shall be performed by a state-certified or third party- or EPA-accredited analytical laboratory.

The analytical methods utilized in this study for on-site monitoring of feedwater and permeate water qualities are described in Task 6, Quality Assurance/ Quality Control (QA/QC).

Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both field and laboratory analytical procedures.

For the water quality parameters requiring analysis at a state-certified or third party- or EPA-accredited laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

Table 4
Sample Water Quality Data Collection Matrix

Monitoring Location (Refer to Figure 2) (1)		Twice per Day		Once per Day					Once Every 5 Days		
		pH	**Nitrate**	**Turbidity**	**Silt Density Index**	**Other Potential Foulants** (2)	**Alka-linity**	**Calcium Hardness**	**Limiting Salt Cation** (3) (4)	**Limiting Salt Anion** (3) (4)	**Other Scalants** (3) (4)
1	Raw Water										
2	Membrane Feed Water										
3	Stage 1 Permeate										
4	Stage 1 Concentrate										
5	Stage 2 Permeate										
6	System Concentrate										
7	System Permeate										
8	Blended Product Water										

(1) Adopt the operational data collection locations to the particular geometry of the membrane system
(2) If identified from raw water quality analysis, Task 1
(3) As determined from raw water quality analysis, Task 1
(4) Limiting salts shall include one or more of the following: $CaSO_4$, $BaSO_4$, $SrSO_4$, SiO_2, and CaF_2

8.4 Analytical Schedule

The minimum monitoring frequency for the required water quality parameters is presented in Table 4. At the discretion of the FTO, the water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling.

Sample collection frequency and protocol shall be defined explicitly by the FTO in the PSTP; however, to the extent possible, analyses for inorganic water quality parameters shall be performed on water sample aliquots that were obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

8.5 Evaluation Criteria

8.5.1 Nitrate Removal

The primary evaluation criteria will be the ability to meet the degree of nitrate rejection (expressed as a percentage) claimed by the manufacturer for the application being verified.

Provide a graph showing the RO/NF feedwater and permeate nitrate concentrations as a function of elapsed operating time.

Provide a graph of nitrate rejection as a function of elapsed operation time, as defined by the following:

$$\textit{Nitrate Rejection (\%)} = \left(\frac{C_f - C_p}{C_f}\right) x\ 100$$

Where: C_f = Nitrate concentration in the feed water (mg/L)
C_p = Nitrate concentration in the product water (mg/L)

8.5.2 Fouling Indices

Provide graphs of RO/NF system feedwater turbidity and silt density index (SDI) as a function of elapsed operating time.

Provide a table showing maximum, minimum, and average RO/NF system feedwater turbidity and SDI values over the entire period of operation. The table shall include a listing of the RO/NF manufacturer's recommended maximum turbidity and SDI values to ensure satisfactory long-term operation of the RO/NF elements and to ensure that the element warranty is not voided.

8.5.3 Concentrate Stream Limiting Salts

Provide graphs of each limiting salt that was present in the system as a function of elapsed operating time. These graphs are required only where concentration of the salt is greater than theoretical solubility or where chemical conditioning of the feedwater was used to control solubility.

Provide a table showing maximum, minimum, and average concentrate stream scaling indices over the entire period of operation, or where the RO/NF system was operated at more than one feedwater recovery, for each distinct period of operation. Include in the table, percent saturation permitted by the manufacturer of the RO/NF elements used in the study and for which verification is being sought.

9.0 TASK 4: RO/NF CLEANING

9.1 Introduction

During or following the test runs of Task 2, the RO/NF equipment shall require chemical cleaning to restore membrane productivity. The number of cleaning efficiency evaluations shall be determined by the fouling frequency of the RO/NF during each 1,000-hour test period. In the case where the rate of fouling is low and the decreases in normalized product flow or increases in normalized salt passage do not reach chemical cleaning criteria as specified by the Manufacturer in Task 1, chemical cleaning shall be performed after each 1,000-hour test of operation, with an evaluation of cleaning efficiency made by subsequent system operation for a period sufficient to determine cleaning impact.

9.2 Objectives

The objectives of this task are as follows:

- Evaluate the effectiveness of chemical cleaning for reversing losses in normalized product flow or increases in normalized salt passage to the RO/NF system.
- Confirm that Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity for the systems being considered under the conditions being evaluated.

9.3 Work Plan

The RO/NF systems may become fouled during the RO/NF test runs conducted for Task 2. These fouled membranes shall be utilized for the cleaning assessments herein. No additional experiments shall be required to produce fouled membranes; cleaning will only be conducted if fouling causes performance losses to levels recommended by the Manufacturer and as listed in the PSTP. If losses are not sufficient, cleaning will be conducted at the conclusion of each 1000-hour test to assess the cleaning efficiency relative to the degree that such losses were incurred.

Each system shall be chemically cleaned using cleaning equipment (including chemicals) provided by the Manufacturer and cleaning solutions and procedures specified by the FTO in the PSTP. After each chemical cleaning of the membranes, the system shall be restarted at test conditions and operated for a period of 72 hours to monitor response to cleaning of the following productivity indicators:

- Normalized product flow
- Normalized salt passage
- Feed-concentrate differential pressure

Cleaning chemicals and cleaning routines shall be based on the recommendations of the Manufacturer. The PSTP shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the information in Table 5 shall be provided. In addition, a description of all cleaning equipment and its operation shall be included in PSTP.

9.4 Analytical Schedule

9.4.1 Sampling

The pH and temperature of each cleaning solution shall be determined and recorded during various periods of the chemical cleaning procedure, as indicated in Table 5. No other water quality sampling shall be required.

9.4.2 Operational Data Collection

RO/NF system performance data shall be collected immediately preceding cleaning and for 72-hours following return of the system to normal operation (following completion of cleaning). If the Manufacturer's procedures required cleaning with two separate cleaning formulations, the 72-hour operating period shall be performed following the completion of the entire cleaning event (final cleaning formulation).

9.5 Evaluation Criteria

At the conclusion of each chemical cleaning event and upon return of the RO/NF system to operation, system operating data (pressure, flow, conductivity, and temperature) shall be recorded four times per day for a 72-hour period and each performance parameter calculated (normalized product flow, normalized salt passage, and feed-concentrate differential pressure). The twelve data values for each performance parameter shall be averaged to obtain a "post-cleaning" value to be used in cleaning efficiency calculations described in this Task. The efficacy of chemical cleaning for each performance parameter shall be evaluated as noted below, with comparisons drawn from the cleaning efficacy achieved during previous cleaning evaluations (where applicable). Comparison between chemical cleanings shall allow evaluation of the potential for irreversible fouling and projections for usable membrane life.

Two primary measures of cleaning efficiency and restoration of membrane productivity will be examined in this task:

1) The immediate recovery of membrane productivity, considering the value of the productivity indicator at the start of the run, at the end of the run, and after cleaning.

$$NPF\ Recovery(\%) = \frac{\left(NPF_{Cleaned} - NPF_{Fouled}\right)}{\left(NPF_{Original} - NPF_{Fouled}\right)}$$

$$NSP\ Recovery(\%) = \frac{\left(NPF_{Fouled} - NPF_{Cleaned}\right)}{\left(NPF_{Fouled} - NPF_{Original}\right)}$$

$$\Delta P\ Recovery(\%) = \frac{\left(\Delta P_{Fouled} - \Delta P_{Cleaned}\right)}{\left(\Delta P_{Fouled} - \Delta P_{Original}\right)}$$

2) The loss of productivity, considering the value of the productivity indicator at the start of the run and after cleaning:

$$NPF\ Loss(\%) = \left(1 - \frac{NPF_{Cleaned}}{NPF_{Original}}\right)$$

$$NSP\ Increase(\%) = \left(\frac{NSP_{Cleaned}}{NSP_{Original}} - 1\right)$$

$$DP\ Increase\ (\%) = \left(\frac{DP_{Cleaned}}{DP_{Original}} - 1\right)$$

Table 5
Data to be Recorded for Documentation of Cleaning Efficiency

Parameter[1]	Units	First Solution	Second Solution	Notes
Preliminary Flush				
Source				
Flow rate	gpm			
Volume or duration	gal or min			
Cleaning chemicals used				
Cleaning solution batch volume	gal			
Citric acid	lbs			
Sodium tripolyphosphate	lbs			
Trisodium phosphate	lbs			
Sodium EDTA	lbs			
Anionic surfactant	mL			
Hydrochloric acid	mL			
50% Sodium hydroxide	mL			
Other:___________________				Other solution components
Other:___________________				List Proprietary cleaning solution
Solution Recirculation/Soak/Recirculation				
pH				Note initial and final
Temperature	deg C			Note initial and final
Initial recirculation period	minutes			
Initial recirculation pH				
Initial recirculation temperature	deg C			
Appearance of solution				Note color, solids, clarity, etc.
Soak period	hours			
Final recirculation period	minutes			
Final recirculation pH				
Final recirculation temperature	deg C			
Appearance of solution				Note color, solids, clarity, etc.
Final Flush				
Source				
pH				
Flow rate	gpm			
Volume or duration	gal or min			

(1) Provide data for each stage if cleaned separately

10.0 TASK 5: DATA REDUCTION AND PRESENTATION

10.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software, manual recording methods, or both, for recording operational parameters of the RO/NF equipment on a daily basis.

10.2 Objectives

The objectives of this task are as follows:

- Establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for verification purposes.
- Develop a statistical analysis of the data, as described in Test Plans for Equipment Verification Testing for Physical-Chemical Removal of Nitrate by Ion Exchange and RO/NF Processes.

10.3 Work Plan

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Microsoft Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases to diskette should be performed on a weekly basis at a minimum.

In the case when a SCADA system is not available, field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook will provide carbon copies of each page. The original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the RO/NF equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each test run) will be assigned a run number, which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL

11.1 Introduction

Quality assurance and quality control of the operation of the RO/NF equipment and the measured water quality parameters shall be maintained during the verification testing program.

11.2 Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

11.3 Work Plan

Equipment flow rates and associated signals should be verified and verification recorded on a routine basis. A routine daily walk through during operation shall be established to verify that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that any chemicals are being fed at the defined flow rate into a flow stream that is operating at the expected flow rate, such that the chemical concentrations are correct. In-line monitoring equipment such as flow meters, etc. shall be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

11.3.1 Daily QA/QC Verifications

- Chemical feed pump flow rates (verified volumetrically over a specific time period)
- On-line turbidimeter flow rates (verified volumetrically, if employed).

11.3.2 Weekly QA/QC Verifications

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).
- Recalibration of on-line pH meters and/or conductivity meters, if used.

11.3.3 Quarterly QA/QC Verifications

- On-line turbidimeters (clean out reservoirs and recalibrate, if employed)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)

11.3.4 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of feedwater and permeate water quality are described in the section below. Use of either bench-top or on-line field analytical equipment will be acceptable for the verification testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

11.3.4.1 pH. Analyses for pH shall be performed according to Standard Method 4500-H. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual.

11.3.4.2 Turbidity. Turbidity analyses shall be performed according to Standard Method 2130 with either an on-line or bench-top turbidimeter. On-line turbidimeters shall be used for measurement of turbidity in the permeate waters, and either an on-line or bench-top turbidimeter may be used for measurement of the feedwater (and concentrate where applicable).

The FTO shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

11.3.5 Chemical and Biological Samples Shipped Off-Site for Analysis

Total organic carbon (TOC) and UV absorbance samples shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4ºC to the analytical laboratory within 8 hours of sampling. The TOC and UV absorbance samples shall be collected and preserved in accordance with Standard Method 5010B.

Table 6
Analytical Methods

Parameter	Analysis Type			Standard Methods [1] number or Other Method Reference	EPA Method[2]
	Field	On-Line	Lab		
General Water Quality					
pH	X	X		4500-H+ B	150.1 / 150.2
Total alkalinity	X		X	2320 B	
Total Hardness	X		X	2340 C	
Calcium Hardness	X		X	3500-Ca D	
Temperature	X	X		2550 B	
Conductivity	X	X	X		120.1
Total Dissolved Solids		X		2540 C	
Turbidity	X	X	X	2130 B / Method 2	180.1
Color	X		X	2120 B[3]	
Taste and Odor			X		
Inorganic Water Quality					
Calcium	X		X	3500-Ca D / 3111 B / 3120 B	200.7
Magnesium			X		200.7
Sodium			X	3111 B	200.7
Potassium			X		200.7
Ammonia			X		350.3
Strontium			X		200.7
Barium			X	3111 D / 3113 B / 3120 B	200.7 / 200.8
Iron	X		X	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese			X	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Carbonate, CO_3			X	Calculation	
Bicarbonate, HCO_3			X	Calculation	
Sulfate			X	4110 B / 4500-SO4= C, D, F	300.0 / 375.2
Chloride	X	X	X	4110 B / 4500-Cl- D	300
Nitrate	X		X	4110 B / 4500-NO3- D, F	300.0 / 353.2
Fluoride			X	4110 B / 4500-F- B, C, D, E	300
Carbon Dioxide			X	6211 M	
Hydrogen Sulfide			X		376.1/2
Silica, SiO_2			X	3120 B / 4500-Si D, E, F	200.7
Organic Water Quality					
Total organic carbon			X	5310 C	
UV254 absorbance	X		X	5910 B	
AOC/BDOC			X	9217	
Microbiological					
Total coliform			X	9221 / 9222 / 9223	
Heterotrophic Plate Count			X	9215 B	

Notes:

1) Standard Methods Source: 20th Edition of Standard Methods for the Examination of Water and Wastewater, 1999, American Water Works Association.

2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

3) Hach Co. modification of SM 2120 measured in spectrophotometer at 455 nm.

1

Inorganic chemical samples, including arsenic, alkalinity, hardness, aluminum, iron, and manganese, shall be collected and preserved in accordance with Standard Method 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples should be refrigerated at approximately 2 to 8ºC immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 2 to 8ºC. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited Laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8ºC until initiation of analysis.

Samples for analysis of Total Coliforms (TC) and Heterotrophic Plate Counts (HPC) shall be collected in bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 2 to 8°C to the analytical laboratory. Samples shall be processed for analysis by the state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities will be reported as colony forming units per milliliter (cfu/mL).

12.0 OPERATION AND MAINTENANCE

The FTO shall obtain the Manufacturer-supplied Operation and Maintenance (O&M) Manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommended criteria for evaluation of Operations and Maintenance (O&M) Manuals for equipment employing RO/NF treatment.

12.1 Operation

Provide clear and concise recommendations for procedures related to proper operation of the RO/NF treatment systems and equipment. Include as a minimum, information on the following:

- Startup
  - Initial startup of system
  - Restart of the system after prolonged shutdown
- Shutdown and membrane element preservation
  - Short term (less than 48 hours)
  - Intermediate term (48 hours to 1 week)
  - Long Term (more than one week)
- Chemical Feed Systems
  - Type of chemical to be used
  - Dose rate
  - Automation of chemical control system (e.g., pH control of acid feed)
- Tolerance of the system to operating conditions

  - Feed water temperature
  - pH
  - Oxidants (e.g., chlorine)
  - Maximum feed pressure and maximum allowable differential pressure across each stage
- Adjustment to operating parameters
  - Product water flux
  - Recovery

12.2 Maintenance

Provide clear and concise procedures for performing maintenance on the system and its components.

- Explicit instructions for in-situ cleaning of membrane elements
  - Chemicals to be used
  - Guidelines and limits for pH, temperature
  - Procedures for flushing before and after cleaning
  - Recirculation rates and durations

- Instructions for installing or replacing membrane elements into the system.

- Recommended or required maintenance schedules for each piece of equipment.

- A list of spare parts to be kept on hand.

12.2.1 Troubleshooting

- Provide an explicit list of alarm conditions that will be raised by the system.
  - Pressure
  - Temperature
  - pH
  - Pump Failure
  - Chemical feed low tank level
- Indicate which alarm conditions will cause automatic system shutdown and provide instructions for clearing each condition.

- Provide detailed procedures for verifying integrity of membranes, o-rings, etc. on a vessel-by-vessel basis.

13.0 REFERENCES

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